Ejectors of power plants turbine units efficiency and reliability increasing

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Abstract. The functioning of steam turbines condensation systems influence on the efficiency and reliability of a power plant a lot. At the same time, the condensation system operating is provided by basic ejectors, which maintain the vacuum level in the condenser. Development of methods of efficiency and reliability increasing for ejector functioning is an actual problem of up-to-date power engineering.

In the paper there is presented statistical analysis of ejector breakdowns, revealed during repairing processes, the influence of such damages on the steam turbine operating reliability. It is determined, that 3% of steam turbine equipment breakdowns are the ejector breakdowns. At the same time, about 7% of turbine breakdowns are caused by different ejector malfunctions. Developed and approved design solutions, which can increase the ejector functioning indexes, are presented. Intercoolers are designed in separated cases, so the air-steam mixture can't move from the high-pressure zones to the low-pressure zones and the maintainability of the apparatuses is increased. By U-type tubes application, the thermal expansion effect of intercooler tubes is compensated and the heat-transfer area is increased. By the applied nozzle fixing construction, it is possible to change the distance between a nozzle and a mixing chamber (nozzle exit position) for operating performance optimization.

In operating conditions there are provided experimental researches of more than 30 serial ejectors and also high-efficient 3-staged ejector EPO-3-80, designed by authors. The measurement scheme of the designed ejector includes 21 indicator. The results of experimental tests with different nozzle exit positions of the ejector EPO-3-80 stream devices are presented. The pressure of primary stream (water steam) is optimized. Experimental data are well-approved by the calculation results.

Introduction

The operational reliability of steam-turbine units in thermal power plants depends on operating of the condensation systems of the steam turbines. Steam-jet ejectors intended for removal of uncondesable gases such as an air from the condenser volume and vacuum system are among the major technical components of condensation systems. Two global indicators of the equipment operating such as the efficiency and the reliability are considered in the paper.

The reliability is considered as an ability of a device to perform its functions regularly, for a long time. The main function of the ejector is to maintain the vacuum value in the condensation system of the turbine. According to this, main indicators of the efficiency, which influence the vacuum value in the condenser (pressure of the I stage and the length of the performance curve) are also connected with the reliability.

Reliability increasing experience

An analysis of the reliability of steam-turbine units with powers ranging from 60 to 500 MW shows [4, 5] that a substantial number of unplanned shutdowns occur because of failures of auxiliary equipment. In addition, failures of auxiliary equipment do not always lead to shutdown of the turbines, but their economic efficiency is reduced [6]. Based on our own studies and a generalization of the data of [4 – 6], the major faults (defects) in ejector operation are identified for a variety of types of operating steam-gas units. The calculations and operational reliability analysis for the auxiliary equipment in steam-gas units were carried out separately for samples of each type of steam-gas unit. Figure 1 shows the distribution of failures of auxiliary equipment in turbine units. The ordinate is the fraction (%) of failures of individual parts of auxiliary equipment for steam-gas units out of the entire number of failures,

$$d = 100N_i/N_0, \tag{1}$$

where N_i is the number of failures of the i-th component and N_0 is the overall number of failures of auxiliary equipment in a turbine unit.

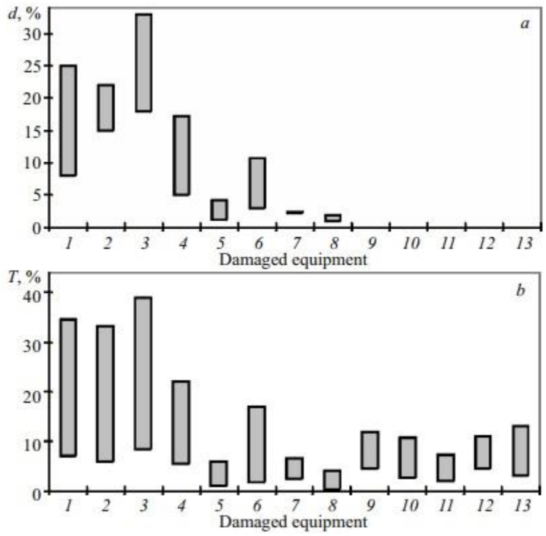

Fig. 1. The distribution of failures (a) and recovery times (b) for auxiliary equipment in turbine systems: 1, condensers; 2, electrical feed pumps; 3, feed turbopumps; 4, high pressure preheaters; 5, low pressure preheaters; 6, gland seal preheaters; 7, ejectors; 8, deaerators; 9, circulation pumps; 10, condensate pumps; 11, booster pumps; 12, armature; and 13, piping

The spread in *d* (1) corresponds to the different types of turbine units. The distribution of the recovery time after failure as a fraction of the overall time for recovery from all damage to auxiliary equipment of a given type of turbine was determined in similar fashion (Fig. 1*b*). An analysis of the data in Fig. 1 shows that ejector failures represent 2.5% of all failures of auxiliary equipment in steam-turbine units and 2.4 – 4.3% of the entire recovery time for auxiliary equipment is expended in recovery from these failures. The recovery times after an ejector failure range from 11 to 132 h. It is very important to note that, based on information from operating personnel and reports on power plants, in most cases failures of ejectors lead to shutdown of the turbine system.

An analysis of the reasons for the unplanned turbine shutdowns owing to breakdowns of auxiliary equipment showed that 7% of these shutdowns are associated with damage to ejectors (Fig. 2). Based on an analysis of the susceptibility to damage of steam-jet ejectors in steam turbines of various kinds from different manufacturers, it was found that the fraction of failures of auxiliary equipment is roughly the same (have similar values) for all these steam turbine units and is independent of the turbine power or type.

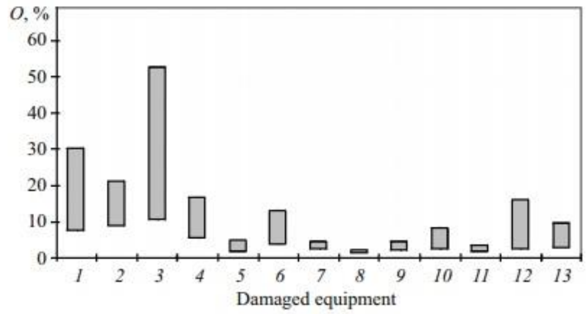

Fig. 2. Fraction of failures of auxiliary equipment responsible for turbine shutdowns: 1, condensers; 2, electrical feed pumps; 3, feed turbopumps; 4, high pressure preheaters; 5, low pressure preheaters; 6, gland seal preheaters; 7, ejectors; 8, deaerators; 9, circulation pumps; 10, condensate pumps; 11, booster pumps; 12, armature; and 13, piping

As a rule, steam turbine units have four steam-jet ejectors (two main ejectors, one seal ejector, and one for startup). The main and seal ejectors have a feature in common: coolers for the steam-air mixture. This means that they can be treated as a single subsystem in the analysis.

Basing on the ejector testing experience, the general malfunctions of the ejector functioning were listed:

- the general or the starting ejector don't maintain a necessary pressure value in the condenser while the turbine is being activating;
- the general ejector doesn't maintain required (standard) pressure value in the condenser while the turbine in being functioning;
- the ejector is functioning in unstable mode, with a changeable inlet pressure and discontinuous exhast at the outlet;
- knocks in the case, too much steam in the last stage, water, threw out from the outlet are fixed.

It is important to keep in mind, that several ejector malfunctions can be cause by the violatons of condenser functioning. For example, when the air-steam mixture temperature in the condenser outlet is increasing and at the same time the circulated water flow rate is low or it's inlet temperature is high, or heat transfer surface is polluted, it brings to ejector inlet pressure increasing and because of that, the required pressure in the condenser is not supported. High inlet pressure of the ejector can be also caused by the big amount of steam, transferred to the condenser outlet passing over the heat transfer surface (for example, if the condenser part is turned off and the outlet of this part is opened).

Considered at different power staions, reason of the inlet pressure decreasing when the air flow rate is standart, usually is insufficient flow rate or the working steam (primary stream). It can be connected with its lower pressure or contamination of nozzles and steam grids.

High air-steam mixture flow rate in the inlet of the ejector can be caused by a thinness of a valve of turned off reserve or starting ejector. The inlet pressure of the 2d and the 3d stages increasing can be connected with the high temperature of an inlet air-steam mixture. It is determined by the high temperature and small value of mass flow rate of the condensate upstream the coolers, pollution or flooding of the cooler heat transferring surface.

Recirculation of the air-steam mixture part through one of the stages causes an increased load of this stage, comparing to load with a value of an air flow rate, which was fixed. It can be connected with emptying of the intercooler drainage water lock or depressurization of partitions between the intercoolers – for ejectors with intercoolers designed in a single case.

Knocks (hydraulic shocks) inside the case are usually the indication of the intercooler flooding because of the drainage contamination or because of the cooling water (condensate) getting into the steam volume through broken tubes. During the cooler flooding, the outlet of the diffuser of this stage can be also blocked. It brings to the increasing of the leaving the diffuser mixture pressure and to periodic breaks through the water layer, which causes hydraulic shocks. When the intercooler of the last stage flooding, a steaming of the ejector can be observed, i.e. steam throwing out from the last stage outlet can be seen. This steam can't be condensed because of the heat transferring surface decreasing. Water drops, which are taken by a steam with a itself also can be fixed.

Breakdowns of ejector coolers [3, 5, 6] are mainly caused by corrosive wear of piping from working steam entering the ejector with a high content of aggressive gases from the deaerator gas mixture, as well as by erosion by wet steam from the turbine seals. When the velocity of the steam entering the apparatus is high, vibrational damage to the pipes can also occur. We have systematized the major effects which have a significant influence on the operating efficiency and reliability of steam-jet ejectors during steam turbine operation, these are technical or technological decisions or defects, which were designed or created in the ejector along its life cycle:

— entrainment of cinder and hail onto the ejector nozzles;
— misalignment of the ejector nozzles and diffusers;
— incorrect exit nozzle position set;
— erroneous assembly of the steam-jet apparatus after repair of an ejector involving a mismatch of the nozzle to the number of the stage, unreliable attachment of the mixing chamber, etc.;
— washing of the gasket between the turbine panel and the barriers in the ejector housing;
— seal failure in the roller junctions of the pipes to the pipe panels of the coolers;
— incorrect pipe material choosed;
— partition thinness inside the case;
— development of flaws in the drain pipes from the ejector stages;
— damaged (erosion and corrosion) heat exchange surfaces in the ejector coolers.

A study of the state of the piping in the ejector seal coolers EU-8M and EU-16 on K-300-240 and K-500-240 turbines at the Reftinskaya GRÉS plant showed that the reason for their unsatisfactory operation is damage to the piping seals [7]. The ejector was partially disassembled and the damaged pipes were hydropressed and plugged periodically during times when the unit was shut down. The pipes in the ejector coolers EU-8M and EU-16 are made of MNZh5-1 alloy, the pipe diameters are 19.17 mm, and the operating lifetime is 20 – 25 years. An analysis of pipe samples showed that the reason for the damage to the pipes in the cooler is local corrosion of their inner surface, which shows up as pitting and the formation of longitudinal cracks.

The operating conditions for the water-treatment system at the Refti GRÉS plant provide for an ammonia feed in the main condensate after the unit desalination system ahead of the injector. This measure should ensure coupling of the carbon dioxide and a higher pH for the condensate. However, ammonia, hydrazine, amines, and nitrogen-containing reagents in the water cause pitting and intercrystallite corrosion of pipes made of copper alloys, especially in sites with elevated stresses: bends, rolling, etc. In particular, the presence of ammonia in the condensate caused cracks and pitting to develop in the pipes.

Piping was also damaged in the coolers for stage I, usually in the zone where the steam-air mixture enters the pipe bundle. An inspection of the piping systems showed that vibrational damage occurred in the peripheral piping, with cracks in the piping panel and lower barrier. Vibration calculations of the piping systems of standard coolers for EU-8M and EU-16 ejectors showed that the amplitude of the vibrations of the pipes in the outer rows is unacceptably high and can lead to vibrational damage to the pipes. This indicates that the vibrational reliability of the piping system is unsatisfactory and there is a need for special steps to eliminate his kind of damage. Based on our studies, we have formulated the following basic conclusions and recommendations:
— the damage to the surfaces of the cooler pipes of the EU-8M and EU-16 ejectors at the Refti GRÉS plant was mainly caused by local corrosion (pitting and longitudinal cracks) by cooling water (main condensate) containing ammonia, which is introduced into the water ahead of the ejectors and causes this kind of corrosion;
— damage to the cooler pipes is also caused by unsatisfactory vibrational reliability of the piping systems;
— the presence of ammonia in the condensate limits the possibility of using copper alloys, so it is better to replace the pipes of MNZh5-1 alloy with stainless steel piping;
— in order to increase the operating efficiency of the heat-exchange surface of the coolers, it is best to use profiled pipes; positive experience with these recommendations can be found elsewhere [1, 2, 8, 9];
— in order to improve the air tightness of the roller junctions of the piping systems of the coolers, a new method for attaching the pipes in the piping panels should be used [1, 2] and has been approved for similar apparatus;
— for the purpose of increasing the vibration reliability of the coolers, it is necessary to change the piping bundle from 1917 diameter pipes of MNZh5-1 alloy to 1614 diameter pipes of 12Kh18N10T alloy, which will increase the heat exchange surface area, with a change in the arrangement of the transverse barriers of the piping systems and installation of special damping belts (clamps) at the bends in the pipes. All of these recommendations have already been implemented in the course of modernizing the coolers for 12 EU-8M and EU-16 ejectors. Personnel at the thermal power plants where these changes have been made confirm the effectiveness of these steps.

The approaches proposed by us for modernization of commercial ejectors have already been used in rebuilding more than 80 steam-jet ejectors (EP-3-2, EP-3-3, EP-3-600, EP-3-700, EP-3-25, EP-3-50, EU-6, EU-8M, EU-16, PS-100, and KhE-65). The accumulated operational experience demonstrates the efficiency and reliability of the modernized ejectors for the end seals of turbines. Test data on the modernized ejectors confirm the computations, as well as the appropriateness and effectiveness of the technical solutions carried out in these systems.

As an another result of the reliability investigating, all the recommendations, formulated in the paper, were applied in the design of a new ejector EPO-3-80 for Surgutskaya GRES-1. In the efficiency section the results of its operating characteristics are presented.

Efficiency research results

The efficiency increasing of the new designed ejector was investigated by commercial tests of the ejector, set on the Surgutskaya GRES-1 station. For the experiment providing a measurement scheme, consisted of 21 measurement points, was designed. A measurement scheme includes pressure and temperature sensors upstream and downstream each diffuser and each intercooler. Temperatures are also being measured before and after each intercooler. The flow rates of the cooling water and the air in the outlet are also being measured at every experimental mode. The scheme is presented on fig.3.

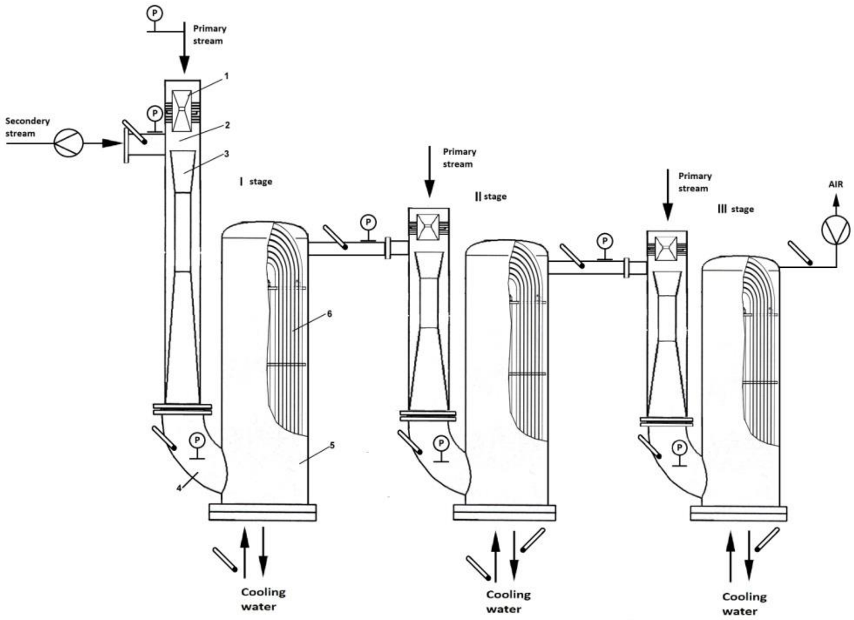

Fig. 3. Measurement sheme of EPO-3-80

A measurement scheme includes pressure and temperature sensors upstream and downstream each diffuser and each intercooler. Temperatures are also being measured before and after each intercooler. The flow rates of the cooling water and the air in the outlet are also being measured at every experimental mode.

For the efficiency increasing a new nozzle fixing module was designed. It is believed, that by changing the nozzle exit position in the ejector, the characteristics of the ejector functioning can be improved. The ejector performance curve is usually a dependence of the pressure in the injection chamber on the flow rate of a secondary stream. The performance curve consists of two linear parts: a working mode and an overloaded mode. Functioning on the overloaded mode is connected with an extremely sharp increasing. Looking for the efficiency, we have to operate the ejector on the working mode, keeping at the same time as low injection pressure as possible. Using a new module of the nozzle fixing, a series of experiments with different nozzle exit positions were provided. On the fig.4 it is presented a performance curves comparing for two different nozzle exit positions (NXP) with different pressures of the primary stream.

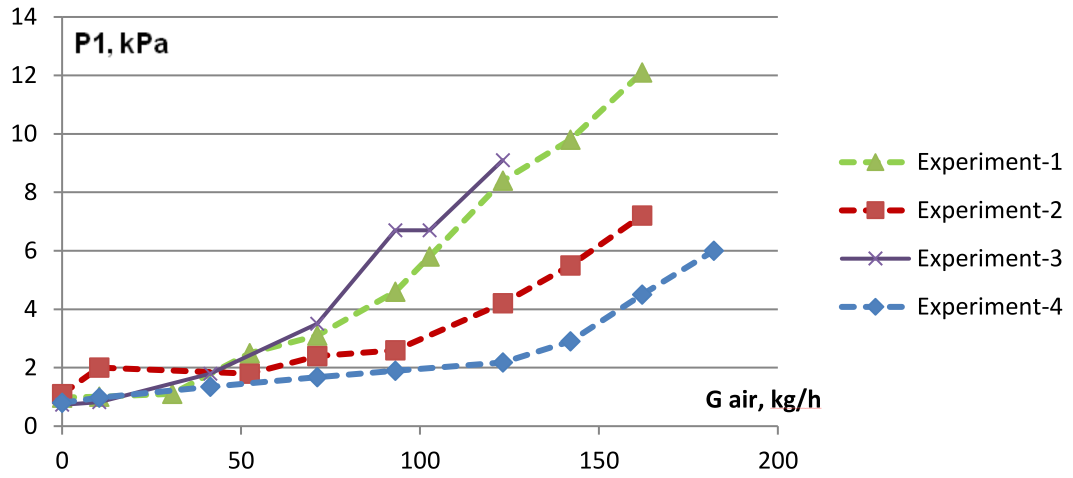

Fig. 4. Performance curves of configuration modes.
Experiments: 1 – NXP1, P=0,6MPa; 2 – NXP1, P=0,7 MPa; 3 – NXP2, P=0,6 MPa; 4 – NXP2, P=0,7 MPa

By changing the position step by step and testing different primary stream pressures, the optimal (most efficient) characteristic mode was found. As it is shown on the fig.4, the performance curve of the 4th experiment corresponds to the longest working mode and to the lowest pressure of the injection chamber along the whole air flow rate.

As a result of the efficiency increasing, the ejector performance curve is compared to other ejectors curves. The characteristics of other ejectors were gotten from the experimental tests of different ejector types on other power stations. The comparison is presented on fig. 5.

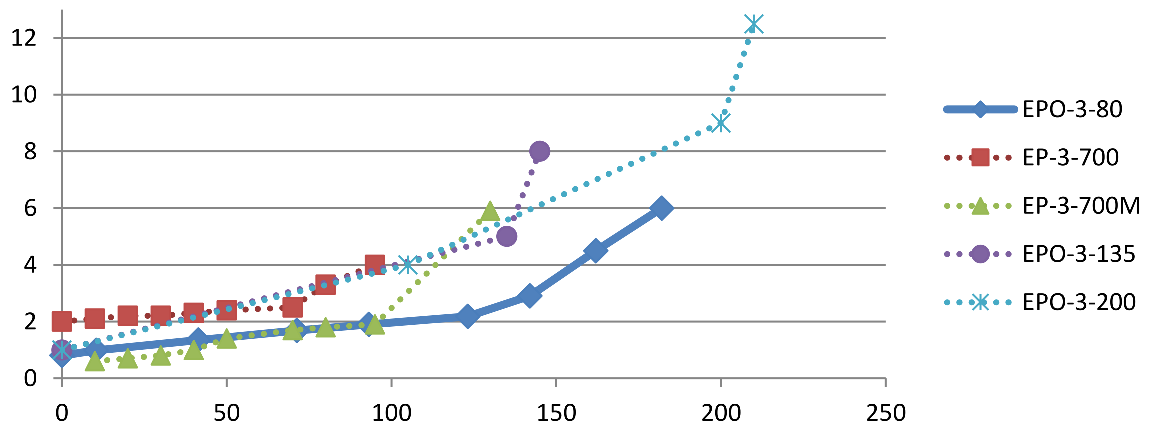

Fig. 5. Performance curves of different ejecotrs

Also as comparing performance curves of different modes, the way to choose the most efficient ejector performance – is to compare the length of the working mode of each ejector and the pressure on it. As it is shown, the EPO-3-80 curve corresponds to the lowest pressure in the area from G_{air}=100 kg/h. Comparing to existing serial ejectors, EPO-3-80 should be considered as the most efficient one.

Conclusion

To sum up the reliability and efficiency investigations, it should be managed that in ejector modernization, these two concepts are significantly connected with each other. The new ejector EPO-3-80 was designed as a result of the conclusions of the provided researches.

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